

What is Claimed:

1 1. A method for manufacturing a quantum electronic device, which
2 includes at least one fine feature on a submicron feature, the at least one fine feature to
3 be located on the submicron feature with a tolerance less than an illumination wavelength
4 used to image the device during manufacture, the method comprising the steps of:

5 5 a) providing a quantum electronic device preform including the
6 submicron feature on a top surface;

7 7 b) illuminating the top surface of the quantum electronic device preform
8 with light having the illumination wavelength;

9 9 c) imaging the top surface of the quantum electronic device preform
10 with a digital camera to produce an alignment image of the top surface which includes a
11 matrix of pixels, the alignment image being scaled such that each pixel has a width
12 corresponding to a constant distance on the top surface of the quantum electronic device
13 preform, the constant distance being less than half of the illumination wavelength;

14 14 d) defining an image coordinate system for the top surface of the
15 quantum electronic device preform using the alignment image and the constant distance;

16 16 e) determining coordinates of a reference point and an orientation of the
17 submicron feature of the top surface of the quantum electronic device preform in the
18 image coordinate system using the alignment image;

19 19 f) determining initial coordinates of a beam spot of a micro-machining
20 laser in the image coordinate system using the alignment image;

21 21 g) aligning the beam spot of the micro-machining laser over a portion of
22 the submicron feature of the quantum electronic device preform using the coordinates of
23 the reference point and the orientation of the submicron feature determined in step (e)
24 and the initial coordinates of the beam spot determined in step (f); and

25 h) machining device material of the quantum electronic device preform
26 with the micro-machining laser to form the at least one fine feature on the submicron
27 feature, completing the quantum electronic device.

1 2. The method according to claim 1, wherein the quantum electronic
2 device is at least one of a quantum cellular automaton, a coupled quantum dot device, or a
3 resonant tunneling device.

1 3. The method according to claim 1, wherein step (f) includes the steps
2 of:

3 f1) ablation a calibration mark in an alignment section of the top surface
4 of the quantum electronic device preform with the micro-machining laser; and

5 f2) determining a location of a center of the calibration mark in the
6 alignment image;

7 f3) using the location of the center of the calibration mark in the
8 alignment image and the image coordinate system defined in step (d) to determine the
9 initial coordinates of the beam spot of the micro-machining laser in the image coordinate
10 system.

1 4. The method according to claim 3, wherein step (d) includes the steps
2 of:

3 d1) ablation a second calibration mark in the alignment section of the top
4 surface of the quantum electronic device preform with the micro-machining laser, the
5 second calibration mark located such that centers of the two calibration marks are a
6 predetermined distance apart;

7 d2) determining the constant distance based on a number of pixels
8 between the centers of the two calibration marks in the alignment image; and

9 d3) using locations of the two calibration marks in the alignment image
10 and the constant distance determined in step (d2) to define the image coordinate system
11 for the top surface of the quantum electronic device preform.

1 5. The method according to claim 3, wherein:

2 the constant distance is a predetermined distance; and

3 step (d) includes using the location of the center of the calibration mark in
4 the alignment image, the matrix of pixels, and the constant distance to define the image
5 coordinate system for the top surface of the quantum electronic device preform.

1 6. The method according to claim 3, wherein:

2 the quantum electronic device preform includes two reference marks,
3 located such that the two reference marks have respective centers that are a
4 predetermined distance apart; and

5 step (d) includes the steps of;

6 d1) determining the constant distance based on a number of
7 pixels between the centers of the two reference marks in the alignment image; and

8 d2) using the location of the center of the calibration mark in the
9 alignment image determined in step (f2) and the constant distance determined in
10 step (d1) to define the image coordinate system for the top surface of the quantum
11 electronic device preform.

1 7. The method according to claim 3, wherein:

2 the submicron feature of the quantum electronic device preform is formed of
3 the device material, which has a device machining threshold;

4 the alignment section of the top surface of the quantum electronic device
5 preform is coated with a coating material having a coating ablation threshold, the coating
6 ablation threshold being less than the device machining threshold;

7 step (f1) includes operating the micro-machining laser with an alignment
8 peak fluence to ablate the calibration mark in only the coating material of the alignment
9 section, the alignment peak fluence being less than the device machining threshold and
10 greater than the coating ablation threshold; and

11 step (h) includes operating the micro-machining laser with a machining peak
12 fluence to machine the at least one fine feature in the device material of the submicron
13 feature, the machining peak fluence being greater than the device machining threshold.

1 8. The method according to claim 1, wherein:

2 a light beam of the micro-machining laser propagates along a beam path
3 including;

4 a transversely moveable pinhole mask having a pinhole located in the
5 beam path; and

6 reducing optics to produce the beam spot on the top surface of the
7 quantum electronic device preform having a beam spot diameter smaller than a
8 pinhole diameter of the pinhole; and

9 step (g) includes aligning the beam spot of the micro-machining laser over
10 the portion of the submicron feature of the quantum electronic device preform by moving
11 the transversely moveable pinhole mask a scaled amount based on a ratio of the pinhole
12 diameter to the beam spot diameter.

1 9. The method according to claim 1, wherein step (g) includes aligning
2 the beam spot of the micro-machining laser over the portion of the submicron feature of
3 the quantum electronic device preform by moving the quantum electronic device preform.

1 10. The method according to claim 1, wherein the micro-machining laser
2 is one of an ultrafast laser or an excimer laser.

1 11. The method according to claim 1, wherein:

2 the micro-machining laser is an ultrafast laser;

3 a full width at half maximum (FWHM) of the beam spot of the micro-
4 machining laser on the top surface is diffraction limited; and

5 step (h) includes operating the micro-machining laser with a machining
6 fluence to machine the at least one fine feature in the device material of the submicron
7 feature, the machining fluence being such that a diameter of an area of the top surface
8 machined by a pulse of the ultrafast laser is less than the FWHM of the beam spot.

1 12. The method according to claim 1, wherein machining the device
2 material in step (h) includes one of ablating the device material or permanently altering a
3 structure of the device material.

1 13. A method for manufacturing a micro-optical device, which includes at
2 least one fine feature on a submicron feature, the at least one fine feature to be located on
3 the submicron feature with a tolerance less than an illumination wavelength used to image
4 the device during manufacture, the method comprising the steps of:

5 a) providing a micro-optical device preform including the submicron
6 feature on a top surface;

7 b) illuminating the top surface of the micro-optical device preform with
8 light having the illumination wavelength;

9 c) imaging the top surface of the micro-optical device preform with a
10 digital camera to produce an alignment image of the top surface which includes a matrix of
11 pixels, the alignment image being scaled such that each pixel has a width corresponding to

12 a constant distance on the top surface of the micro-optical device preform, the constant
13 distance being less than half of the illumination wavelength;

14 d) defining an image coordinate system for the top surface of the micro-
15 optical device preform using the alignment image and the constant distance;

16 e) determining coordinates of a reference point and an orientation of the
17 submicron feature of the top surface of the micro-optical device preform in the image
18 coordinate system using the alignment image;

19 f) determining initial coordinates of a beam spot of a micro-machining
20 laser in the image coordinate system using the alignment image;

21 g) aligning the beam spot of the micro-machining laser over a portion of
22 the submicron feature of the micro-optical device preform using the coordinates of the
23 reference point and the orientation of the submicron feature determined in step (e) and
24 the initial coordinates of the beam spot determined in step (f); and

25 h) machining device material of the micro-optical device preform with
26 the micro-machining laser to form the at least one fine feature on the submicron feature,
27 completing the micro-optical device.

1 14. The method according to claim 13, wherein the micro-optical device
2 is at least one of a multifunction optical array, a diffractive optical element, or a beam
3 shaper.

1 15. The method according to claim 13, wherein step (f) includes the
2 steps of:

3 f1) ablating a calibration mark in an alignment section of the top surface
4 of the micro-optical device preform with the micro-machining laser; and

5 f2) determining a location of a center of the calibration mark in the
6 alignment image;

7 f3) using the location of the center of the calibration mark in the
8 alignment image and the image coordinate system defined in step (d) to determine the
9 initial coordinates of the beam spot of the micro-machining laser in the image coordinate
10 system.

1 16. The method according to claim 15, wherein step (d) includes the
2 steps of:

3 d1) ablation a second calibration mark in the alignment section of the top
4 surface of the micro-optical device preform with the micro-machining laser, the second
5 calibration mark located such that centers of the two calibration marks are a
6 predetermined distance apart;

7 d2) determining the constant distance based on a number of pixels
8 between the centers of the two calibration marks in the alignment image; and

9 d3) using locations of the two calibration marks in the alignment image
10 and the constant distance determined in step (d2) to define the image coordinate system
11 for the top surface of the micro-optical device preform.

1 17. The method according to claim 15, wherein:

2 the constant distance is a predetermined distance; and

3 step (d) includes using the location of the center of the calibration mark in
4 the alignment image, the matrix of pixels, and the constant distance to define the image
5 coordinate system for the top surface of the micro-optical device preform.

1 18. The method according to claim 15, wherein:

2 the micro-optical device preform includes two reference marks, located such
3 that the two reference marks have respective centers that are a predetermined distance
4 apart; and

5 step (d) includes the steps of;

6 d1) determining the constant distance based on a number of
7 pixels between the centers of the two reference marks in the alignment image; and

8 d2) using the location of the center of the calibration mark in the
9 alignment image determined in step (f2) and the constant distance determined in
10 step (d1) to define the image coordinate system for the top surface of the micro-
11 optical device preform.

1 19. The method according to claim 15, wherein:

2 the submicron feature of the micro-optical device preform is formed of the
3 device material, which has a device machining threshold;

4 the alignment section of the top surface of the micro-optical device preform
5 is coated with a coating material having a coating ablation threshold, the coating ablation
6 threshold being less than the device machining threshold;

7 step (f1) includes operating the micro-machining laser with an alignment
8 peak fluence to ablate the calibration mark in only the coating material of the alignment
9 section, the alignment peak fluence being less than the device machining threshold and
10 greater than the coating ablation threshold; and

11 step (h) includes operating the micro-machining laser with a machining peak
12 fluence to machine the at least one fine feature in the device material of the submicron
13 feature, the machining peak fluence being greater than the device machining threshold.

1 20. The method according to claim 13, wherein:

2 a light beam of the micro-machining laser propagates along a beam path
3 including;

4 a transversely moveable pinhole mask having a pinhole located in the
5 beam path; and

6 reducing optics to produce the beam spot on the top surface of the
7 micro-optical device preform having a beam spot diameter smaller than a pinhole
8 diameter of the pinhole; and

9 step (g) includes aligning the beam spot of the micro-machining laser over
10 the portion of the submicron feature of the micro-optical device preform by moving the
11 transversely moveable pinhole mask a scaled amount based on a ratio of the pinhole
12 diameter to the beam spot diameter.

1 21. The method according to claim 13, wherein step (g) includes aligning
2 the beam spot of the micro-machining laser over the portion of the submicron feature of
3 the micro-optical device preform by moving the micro-optical device preform.

1 22. The method according to claim 13, wherein the micro-machining
2 laser is one of an ultrafast laser or an excimer laser.

1 23. The method according to claim 13, wherein:

2 the micro-machining laser is an ultrafast laser;

3 a full width at half maximum (FWHM) of the beam spot of the micro-
4 machining laser on the top surface is diffraction limited; and

5 step (h) includes operating the micro-machining laser with a machining
6 fluence to machine the at least one fine feature in the device material of the submicron
7 feature, the machining fluence being such that a diameter of an area of the top surface
8 machined by a pulse of the ultrafast laser is less than the FWHM of the beam spot.

1 24. The method according to claim 13, wherein machining the device
2 material in step (h) includes one of ablating the device material or permanently altering a
3 structure of the device material.

1 25. A method for manufacturing a micro-mechanical oscillator, which
2 includes at least one fine feature on a submicron feature, the at least one fine feature to
3 be located on the submicron feature with a tolerance less than an illumination wavelength
4 used to image the device during manufacture, the method comprising the steps of:

5 a) providing a micro-mechanical oscillator preform including the
6 submicron feature on a top surface;

7 b) illuminating the top surface of the micro-mechanical oscillator
8 preform with light having the illumination wavelength;

9 c) imaging the top surface of the micro-mechanical oscillator preform
10 with a digital camera to produce an alignment image of the top surface which includes a
11 matrix of pixels, the alignment image being scaled such that each pixel has a width
12 corresponding to a constant distance on the top surface of the micro-mechanical oscillator
13 preform, the constant distance being less than half of the illumination wavelength;

14 d) defining an image coordinate system for the top surface of the micro-
15 mechanical oscillator preform using the alignment image and the constant distance;

16 e) determining coordinates of a reference point and an orientation of the
17 submicron feature of the top surface of the micro-mechanical oscillator in the image
18 coordinate system using the alignment image;

19 f) determining initial coordinates of a beam spot of a micro-machining
20 laser in the image coordinate system using the alignment image;

21 g) aligning the beam spot of the micro-machining laser over a portion of
22 the submicron feature of the micro-mechanical oscillator preform using the coordinates of
23 the reference point and the orientation of the submicron feature determined in step (e)
24 and the initial coordinates of the beam spot determined in step (f); and

25 h) machining device material of the micro-mechanical oscillator preform
26 with the micro-machining laser to form the at least one fine feature on the submicron
27 feature, completing the micro-mechanical oscillator.

1 26. The method according to claim 25, wherein step (f) includes the
2 steps of:

3 f1) ablation a calibration mark in an alignment section of the top surface
4 of the micro-mechanical oscillator preform with the micro-machining laser; and

5 f2) determining a location of a center of the calibration mark in the
6 alignment image;

7 f3) using the location of the center of the calibration mark in the
8 alignment image and the image coordinate system defined in step (d) to determine the
9 initial coordinates of the beam spot of the micro-machining laser in the image coordinate
10 system.

1 27. The method according to claim 26, wherein step (d) includes the
2 steps of:

3 d1) ablation a second calibration mark in the alignment section of the top
4 surface of the micro-mechanical oscillator preform with the micro-machining laser, the
5 second calibration mark located such that centers of the two calibration marks are a
6 predetermined distance apart;

7 d2) determining the constant distance based on a number of pixels
8 between the centers of the two calibration marks in the alignment image; and

9 d3) using locations of the two calibration marks in the alignment image
10 and the constant distance determined in step (d2) to define the image coordinate system
11 for the top surface of the micro-mechanical oscillator preform.

1 28. The method according to claim 26, wherein:

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2 the constant distance is a predetermined distance; and

3 step (d) includes using the location of the center of the calibration mark in
4 the alignment image, the matrix of pixels, and the constant distance to define the image
5 coordinate system for the top surface of the micro-mechanical oscillator preform.

1 29. The method according to claim 26, wherein:

2 the micro-mechanical oscillator preform includes two reference marks,
3 located such that the two reference marks have respective centers that are a
4 predetermined distance apart; and

5 step (d) includes the steps of;

6 d1) determining the constant distance based on a number of
7 pixels between the centers of the two reference marks in the alignment image; and

8 d2) using the location of the center of the calibration mark in the
9 alignment image determined in step (f2) and the constant distance determined in
10 step (d1) to define the image coordinate system for the top surface of the micro-
11 mechanical oscillator preform.

1 30. The method according to claim 26, wherein:

2 the submicron feature of the micro-mechanical oscillator preform is formed
3 of the device material, which has a device machining threshold;

4 the alignment section of the top surface of the micro-mechanical oscillator
5 preform is coated with a coating material having a coating ablation threshold, the coating
6 ablation threshold being less than the device machining threshold;

7 step (f1) includes operating the micro-machining laser with an alignment
8 peak fluence to ablate the calibration mark in only the coating material of the alignment

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9 section, the alignment peak fluence being less than the device machining threshold and
10 greater than the coating ablation threshold; and

11 step (h) includes operating the micro-machining laser with a machining peak
12 fluence to machine the at least one fine feature in the device material of the submicron
13 feature, the machining peak fluence being greater than the device machining threshold.

1 31. The method according to claim 25, wherein:

2 a light beam of the micro-machining laser propagates along a beam path
3 including;

4 a transversely moveable pinhole mask having a pinhole located in the
5 beam path; and

6 reducing optics to produce the beam spot on the top surface of the
7 micro-mechanical oscillator preform having a beam spot diameter smaller than a
8 pinhole diameter of the pinhole; and

9 step (g) includes aligning the beam spot of the micro-machining laser over
10 the portion of the submicron feature of the micro-mechanical oscillator preform by moving
11 the transversely moveable pinhole mask a scaled amount based on a ratio of the pinhole
12 diameter to the beam spot diameter.

1 32. The method according to claim 25, wherein step (g) includes aligning
2 the beam spot of the micro-machining laser over the portion of the submicron feature of
3 the micro-mechanical oscillator preform by moving the micro-mechanical oscillator
4 preform.

1 33. The method according to claim 25, wherein the micro-machining
2 laser is one of an ultrafast laser or an excimer laser.

1 34. The method according to claim 25, wherein a resonance spectrum of
2 the micro-mechanical oscillator is tuned by the at least one fine feature machined on the
3 submicron feature.

1 35. The method according to claim 34, wherein:

2 step (a) includes the steps of;

3 a1) activating the micro-mechanical oscillator;

4 a2) determining an initial resonance spectrum of the micro-
5 mechanical oscillator;

6 a3) comparing the initial resonance spectrum determined in step
7 (a2) to a predetermined resonance spectrum; and

8 a4) determining a desired shape on the submicron feature of the
9 at least one fine feature based on the comparison in step (a3); and

10 step (h) includes machining the at least one fine feature to have the desired
11 shape on the submicron feature determined in step (a4) with the micro-machining laser.

1 36. The method according to claim 25, wherein:

2 the micro-machining laser is an ultrafast laser;

3 a full width at half maximum (FWHM) of the beam spot of the micro-
4 machining laser on the top surface is diffraction limited; and

5 step (h) includes operating the micro-machining laser with a machining
6 fluence to machine the at least one fine feature in the device material of the submicron
7 feature, the machining fluence being such that a diameter of an area of the top surface
8 machined by a pulse of the ultrafast laser is less than the FWHM of the beam spot.

1 37. The method according to claim 25, wherein machining the device
2 material in step (h) includes one of ablating the device material or permanently altering a
3 structure of the device material.

1 38. A method for manufacturing a mold for microstructures, which
2 includes at least one fine feature on a submicron feature, the at least one fine feature to
3 be located on the submicron feature with a tolerance less than an illumination wavelength
4 used to image the mold during manufacture, the method comprising the steps of:

5 a) providing a mold preform including the submicron feature on a top
6 surface;

7 b) illuminating the top surface of the mold preform with light having the
8 illumination wavelength;

9 c) imaging the top surface of the mold preform with a digital camera to
10 produce an alignment image of the top surface which includes a matrix of pixels, the
11 alignment image being scaled such that each pixel has a width corresponding to a constant
12 distance on the top surface of the mold preform, the constant distance being less than half
13 of the illumination wavelength;

14 d) defining an image coordinate system for the top surface of the mold
15 preform using the alignment image and the constant distance;

16 e) determining coordinates of a reference point and an orientation of the
17 submicron feature of the top surface of the mold preform in the image coordinate system
18 using the alignment image;

19 f) determining initial coordinates of a beam spot of a micro-machining
20 laser in the image coordinate system using the alignment image;

21 g) aligning the beam spot of the micro-machining laser over a portion of
22 the submicron feature of the mold preform using the coordinates of the reference point and

23 the orientation of the submicron feature determined in step (e) and the initial coordinates
24 of the beam spot determined in step (f); and

25 h) ablating mold material of the mold preform with the micro-machining
26 laser to form the at least one fine feature on the submicron feature, completing the mold.

1 39. The method according to claim 38, wherein the microstructures to be
2 formed by the mold are at least one of quantum cellular automata, coupled quantum dot
3 devices, resonant tunneling devices, multifunction optical arrays, diffractive optical
4 elements, beam shapers, microlens arrays, optical diffusers, beam splitters, laser diode
5 correctors, fine pitch gratings, photonic crystals, micro-electrical-mechanical systems,
6 micro-circuitry, polymerase chain reaction microsystems, biochips for detection of
7 hazardous chemical and biological agents, high-throughput drug screening and selection
8 microsystems, micro-surface-acoustic-wave devices, or micro-mechanical oscillators.

1 40. The method according to claim 38, wherein step (f) includes the
2 steps of:

3 f1) ablating a calibration mark in an alignment section of the top surface
4 of the mold preform with the micro-machining laser; and

5 f2) determining a location of a center of the calibration mark in the
6 alignment image;

7 f3) using the location of the center of the calibration mark in the
8 alignment image and the image coordinate system defined in step (d) to determine the
9 initial coordinates of the beam spot of the micro-machining laser in the image coordinate
10 system.

1 41. The method according to claim 40, wherein step (d) includes the
2 steps of:

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3 d1) ablating a second calibration mark in the alignment section of the top
4 surface of the mold preform with the micro-machining laser, the second calibration mark
5 located such that centers of the two calibration marks are a predetermined distance apart;

6 d2) determining the constant distance based on a number of pixels
7 between the centers of the two calibration marks in the alignment image; and

8 d3) using locations of the two calibration marks in the alignment image
9 and the constant distance determined in step (d2) to define the image coordinate system
10 for the top surface of the mold preform.

1 42. The method according to claim 40, wherein:

2 the constant distance is a predetermined distance; and

3 step (d) includes using the location of the center of the calibration mark in
4 the alignment image, the matrix of pixels, and the constant distance to define the image
5 coordinate system for the top surface of the mold preform.

1 43. The method according to claim 40, wherein:

2 the mold preform includes two reference marks, located such that the two
3 reference marks have respective centers that are a predetermined distance apart; and

4 step (d) includes the steps of;

5 d1) determining the constant distance based on a number of
6 pixels between the centers of the two reference marks in the alignment image; and

7 d2) using the location of the center of the calibration mark in the
8 alignment image determined in step (f2) and the constant distance determined in
9 step (d1) to define the image coordinate system for the top surface of the mold
10 preform.

1 44. The method according to claim 40, wherein:

2 the submicron feature of the mold preform is formed of the mold material,
3 which has a mold ablation threshold;

4 the alignment section of the top surface of the mold preform is coated with a
5 coating material having a coating ablation threshold, the coating ablation threshold being
6 less than the mold ablation threshold;

7 step (f1) includes operating the micro-machining laser with an alignment
8 peak fluence to ablate the calibration mark in only the coating material of the alignment
9 section, the alignment peak fluence being less than the mold ablation threshold and
10 greater than the coating ablation threshold; and

11 step (h) includes operating the micro-machining laser with an ablation peak
12 fluence to ablate the at least one fine feature in the mold material of the submicron
13 feature, the ablation peak fluence being greater than the mold ablation threshold.

1 45. The method according to claim 38, wherein:

2 a light beam of the micro-machining laser propagates along a beam path
3 including;

4 a transversely moveable pinhole mask having a pinhole located in the
5 beam path; and

6 reducing optics to produce the beam spot on the top surface of the
7 mold preform having a beam spot diameter smaller than a pinhole diameter of the
8 pinhole; and

9 step (g) includes aligning the beam spot of the micro-machining laser over
10 the portion of the submicron feature of the mold preform by moving the transversely
11 moveable pinhole mask a scaled amount based on a ratio of the pinhole diameter to the
12 beam spot diameter.

1 46. The method according to claim 38, wherein step (g) includes aligning
2 the beam spot of the micro-machining laser over the portion of the submicron feature of
3 the mold preform by moving the mold preform.

1 47. The method according to claim 38, wherein the micro-machining
2 laser is one of an ultrafast laser or an excimer laser.

1 48. The method according to claim 38, wherein:

2 the micro-machining laser is an ultrafast laser;

3 a full width at half maximum (FWHM) of the beam spot of the micro-
4 machining laser on the top surface is diffraction limited; and

5 step (h) includes operating the micro-machining laser with an ablation
6 fluence to ablate the at least one fine feature in the mold material of the submicron
7 feature, the ablation fluence being such that a diameter of an area of the top surface
8 ablated by a pulse of the ultrafast laser is less than the FWHM of the beam spot.

1 49. A method for forming a defect in a photonic crystal, the method
2 comprising the steps of:

3 a) providing a photonic crystal work piece having a top surface
4 including;

5 an alignment section; and

6 a photonic crystal section formed of a plurality of air holes in an
7 interstitial material, each air hole having a diameter less than an illumination
8 wavelength used to image the work piece during defect formation and centers of
9 two of the plurality of air holes being a predetermined distance apart;

10 b) ablating an origin mark in the alignment section of the photonic
11 crystal work piece with a micro-machining laser;

12 c) illuminating the top surface of the photonic crystal work piece with
13 light having the illumination wavelength;

14 d) imaging the top surface of the photonic crystal work piece with a
15 digital camera to produce an alignment image of the top surface which includes a matrix of
16 pixels, the alignment image being scaled such that each pixel has a width corresponding to
17 a constant distance on the top surface of the photonic crystal work piece, the constant
18 distance being less than half of the illumination wavelength;

19 e) determining the constant distance based on a number of pixels in the
20 alignment image between the centers of the two air holes that are separated by the
21 predetermined distance;

22 f) determining a location of a center of the calibration mark in the
23 alignment image and defining an image coordinate system for the top surface of the
24 photonic crystal work piece using the location of the origin mark in the alignment image,
25 the matrix of pixels, and the constant distance determined in step (e);

26 g) determining coordinates of centers of the plurality of air holes of the
27 photonic crystal section of the top surface of the photonic crystal work piece in the image
28 coordinate system using the alignment image;

29 h) determining initial coordinates of a beam spot of the micro-machining
30 laser in the image coordinate system using the location of the origin mark in the alignment
31 image;

32 i) aligning the beam spot of the micro-machining laser over a defect
33 location of the photonic crystal section using the coordinates of the air holes determined in
34 step (g) and the initial coordinates of the beam spot determined in step (h); and

35 j) machining interstitial material at the defect location of the photonic
36 crystal section with the micro-machining laser to form the defect.

1 50. The method according to claim 49, wherein:

2 the interstitial material has a work piece machining threshold;

3 the alignment section of the top surface of the photonic crystal work piece is
4 coated with a coating material having a coating ablation threshold, the coating ablation
5 threshold being less than the work piece machining threshold;

6 step (b) operating the micro-machining laser with an alignment peak fluence
7 to ablate the origin mark in only the coating material of the alignment section, the
8 alignment peak fluence being less than the work piece machining threshold and greater
9 than the coating ablation threshold; and

10 step (j) includes operating the micro-machining laser with a machining peak
11 fluence to machine the interstitial material at the defect location, the machining peak
12 fluence being greater than the work piece machining threshold.

1 51. The method according to claim 49, wherein:

2 a light beam of the micro-machining laser propagates along a beam path
3 including;

4 a transversely moveable pinhole mask having a pinhole located in the
5 beam path; and

6 reducing optics to produce the beam spot on the top surface of the
7 photonic crystal work piece having a beam spot diameter smaller than a pinhole
8 diameter of the pinhole; and

9 step (i) includes aligning the beam spot of the micro-machining laser over
10 the defect location of the photonic crystal section of the photonic crystal work piece by
11 moving the transversely moveable pinhole mask a scaled amount based on a ratio of the
12 pinhole diameter to the beam spot diameter.

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1 52. The method according to claim 49, wherein step (i) includes aligning
2 the beam spot of the micro-machining laser over the defect location of the photonic crystal
3 section of the photonic crystal work piece by moving the photonic crystal work piece.

1 53. The method according to claim 49, wherein the micro-machining
2 laser is one of an ultrafast laser or an excimer laser.

1 54. The method according to claim 49, wherein a transmission spectrum
2 of the photonic crystal is tuned by the defect formed in step (j).

1 55. The method according to claim 54, wherein:

2 step (a) includes the steps of;

3 a1) determining the transmission spectrum of the photonic
4 crystal;

5 a2) comparing the transmission spectrum determined in step (a1)
6 to a predetermined transmission spectrum; and

7 a3) determining a shape of the defect and the defect location
8 based on the comparison in step (a2); and

9 step (j) includes forming the defect at the defect location and having the
10 shape determined in step (a3).

1 56. The method according to claim 49, wherein:

2 the micro-machining laser is an ultrafast laser;

3 a full width at half maximum (FWHM) of the beam spot of the micro-
4 machining laser on the top surface is diffraction limited; and

5 step (j) includes operating the micro-machining laser with a machining
6 fluence to machine the at least one fine feature in the interstitial material of the photonic
7 crystal work piece, the machining fluence being such that a diameter of an area of the top
8 surface machined by a pulse of the ultrafast laser is less than the FWHM of the beam spot.

1 57. The method according to claim 49, wherein machining the interstitial
2 material in step (j) includes one of ablating the interstitial material or permanently altering
3 a refractive index of the interstitial material.

1 58. A method for mass customizing a plurality of microstructures with a
2 laser micro-machining system, each microstructure having at least one of a plurality of
3 customization features, the method comprising the steps of:

4 a) providing a plurality of microstructure preforms, each microstructure
5 preform including a top surface and a submicron feature on the top surface;

6 b) selecting a microstructure preform from the plurality of
7 microstructure preforms and at least one customization feature from the plurality of
8 customization features, the at least one customization feature to be located on the
9 submicron feature with a tolerance less than an illumination wavelength used to image the
10 microstructures during customization;

11 c) coarsely aligning the selected microstructure preform in the laser
12 micro-machining system;

13 d) illuminating the top surface of the selected microstructure preform
14 with light having the illumination wavelength;

15 e) imaging the top surface of the selected microstructure preform with a
16 digital camera to produce an alignment image of the top surface which includes a matrix of
17 pixels, the alignment image being scaled such that each pixel has a width corresponding to
18 a constant distance on the top surface of the selected microstructure preform, the constant
19 distance being less than half of the illumination wavelength;

20 f) defining an image coordinate system for the top surface of the
21 selected microstructure preform using the alignment image and the constant distance;

22 g) determining coordinates of a reference point and an orientation of the
23 submicron feature of the top surface of the selected microstructure preform in the image
24 coordinate system using the alignment image;

25 h) determining initial coordinates of a beam spot of the laser micro-
26 machining system in the image coordinate system using the alignment image;

27 i) aligning the beam spot of the laser micro-machining system over a
28 portion of the submicron feature of the selected microstructure preform using the
29 coordinates of the reference point and the orientation of the submicron feature determined
30 in step (g), the initial coordinates of the beam spot determined in step (h), and the at least
31 one customization feature selected in step (b);

32 j) machining device material of the selected microstructure preform
33 with the laser micro-machining system to form the at least one customization feature
34 selected in step (b) on the submicron feature of the selected microstructure preform to
35 form a customized microstructure; and

36 k) repeating steps (b), (c), (d), (e), (f), (g), (h), (i), and (j) for each of
37 the plurality of microstructure preforms provided in step (a).

1 59. The method according to claim 58, wherein the plurality of
2 microstructures to be mass customized are at least one of microstructure molds, quantum
3 cellular automata, coupled quantum dot devices, resonant tunneling devices, multifunction
4 optical arrays, diffractive optical elements, beam shapers, microlens arrays, optical
5 diffusers, beam splitters, laser diode correctors, fine pitch gratings, photonic crystals,
6 micro-electrical-mechanical systems, micro-circuitry, micro-surface-acoustic-wave devices,
7 or micro-mechanical oscillators.

1 60. The method according to claim 58, wherein step (h) includes the
2 steps of:

3 h1) ablation a calibration mark in an alignment section of the top surface
4 of the selected microstructure preform with the micro-machining laser; and

5 h2) determining a location of a center of the calibration mark in the
6 alignment image;

7 h3) using the location of the center of the calibration mark in the
8 alignment image and the image coordinate system defined in step (f) to determine the
9 initial coordinates of the beam spot of the laser micro-machining system in the image
10 coordinate system.

1 61. The method according to claim 60, wherein step (f) includes the
2 steps of:

3 f1) ablation a second calibration mark in the alignment section of the top
4 surface of the selected microstructure preform with the micro-machining laser, the second
5 calibration mark located such that centers of the two calibration marks are a
6 predetermined distance apart;

7 f2) determining the constant distance based on a number of pixels
8 between the centers of the two calibration marks in the alignment image; and

9 f3) using locations of the two calibration marks in the alignment image
10 and the constant distance determined in step (f2) to define the image coordinate system
11 for the top surface of the selected microstructure preform.

1 62. The method according to claim 60, wherein:

2 the constant distance is a predetermined distance; and

3 step (f) includes using the location of the center of the calibration mark in
4 the alignment image, the matrix of pixels, and the constant distance to define the image
5 coordinate system for the top surface of the selected microstructure preform.

1 63. The method according to claim 60, wherein:

2 the selected microstructure preform includes two reference marks, located
3 such that the two reference marks have respective centers that are a predetermined
4 distance apart; and

5 step (f) includes the steps of;

6 f1) determining the constant distance based on a number of
7 pixels between the centers of the two reference marks in the alignment image; and

8 f2) using the location of the center of the calibration mark in the
9 alignment image determined in step (h2) and the constant distance determined in
10 step (f1) to define the image coordinate system for the top surface of the selected
11 microstructure preform.

1 64. The method according to claim 60, wherein:

2 the submicron features of the plurality of microstructure preforms are
3 formed of the device material, which has a device machining threshold;

4 the alignment sections of the top surfaces of the plurality of microstructure
5 preforms are coated with a coating material having a coating ablation threshold, the
6 coating ablation threshold being less than the device machining threshold;

7 step (h1) includes operating the micro-machining laser with an alignment
8 peak fluence to ablate the calibration mark in only the coating material of the alignment
9 section, the alignment peak fluence being less than the device machining threshold and
10 greater than the coating ablation threshold; and

11 step (j) includes operating the micro-machining laser with a machining peak
12 fluence to machine the at least one fine feature selected in step (b) in the device material
13 of the submicron feature of the selected microstructure preform, the machining peak
14 fluence being greater than the device machining threshold.

1 65. The method according to claim 58, wherein:

2 a light beam of the micro-machining laser propagates along a beam path
3 including;

4 a transversely moveable pinhole mask having a pinhole located in the
5 beam path; and

6 reducing optics to produce the beam spot on the top surface of the
7 selected microstructure preform having a beam spot diameter smaller than a
8 pinhole diameter of the pinhole; and

9 step (i) includes aligning the beam spot of the laser micro-machining system
10 over the portion of the submicron feature of the selected microstructure preform by
11 moving the transversely moveable pinhole mask a scaled amount based on a ratio of the
12 pinhole diameter to the beam spot diameter.

1 66. The method according to claim 58, wherein step (i) includes aligning
2 the beam spot of the laser micro-machining system over the portion of the submicron
3 feature of the selected microstructure preform by moving the selected microstructure
4 preform.

1 67. The method according to claim 58, wherein a micro-machining laser
2 of the laser micro-machining system is one of an ultrafast laser or an excimer laser.

1 68. The method according to claim 58, wherein:

2 a micro-machining laser of the laser micro-machining system is an ultrafast
3 laser;

4 a full width at half maximum (FWHM) of the beam spot of the micro-
5 machining laser on the top surface is diffraction limited; and

6 step (j) includes operating the micro-machining laser with a machining
7 fluence to machine the at least one fine feature in the device material of the submicron
8 feature, the machining fluence being such that a diameter of an area of the top surface
9 machined by a pulse of the ultrafast laser is less than the FWHM of the beam spot.

1 69. The method according to claim 58, wherein machining the device
2 material in step (j) includes one of ablating the device material or permanently altering a
3 structure of the device material.

1 70. A method for repairing a microstructure with a laser micro-machining
2 system, the microstructure including a submicron defect on a top surface, such that
3 machining of the submicron defect is performed with an accuracy of less than an
4 illumination wavelength used to image the microstructure during repair, the method
5 comprising the steps of:

6 a) coupling the defective microstructure to a repair mount, the repair
7 mount including an alignment surface adjacent to the defective microstructure;

8 b) coarsely aligning the repair mount in the laser micro-machining
9 system, such that a beam spot of a micro-machining laser of the laser micro-machining
10 system is incident on the alignment surface of the repair mount;

11 c) ablating a calibration mark in the alignment surface of repair mount
12 with the micro-machining laser;

13 d) illuminating the top surface of the defective microstructure and the
14 alignment surface of the repair mount with light having the illumination wavelength;

15 e) imaging the top surface of the defective microstructure and the
16 alignment surface of the repair mount with a digital camera to produce an alignment
17 image of the top surface which includes a matrix of pixels, the alignment image being
18 scaled such that each pixel has a width corresponding to a constant distance on the
19 imaged surfaces, the constant distance being less than half of the illumination wavelength;

20 f) determining a location of a center of the calibration mark in the
21 alignment image and defining an image coordinate system for the imaged surfaces using
22 the alignment image, the location of the center of the calibration mark in the alignment
23 image, and the constant distance;

24 g) determining coordinates of the submicron defect of the top surface of
25 the defective microstructure in the image coordinate system using the alignment image;

26 h) using the location of the center of the calibration mark in the
27 alignment image and the image coordinate system defined in step (f) to determine initial
28 coordinates of the beam spot of the micro-machining laser in the image coordinate
29 system;

30 i) aligning the beam spot of the micro-machining laser over a portion of
31 the submicron defect of the defective microstructure using the coordinates of the
32 submicron defect determined in step (g) and the initial coordinates of the beam spot
33 determined in step (h); and

34 j) machining device material of the defective microstructure with the
35 micro-machining laser to repair the submicron defect of the defective microstructure.

1 71. The method according to claim 70, wherein the microstructure to be
2 repaired includes at least one of a microstructure mold, a quantum cellular automaton, a
3 coupled quantum dot device, a resonant tunneling device, a multifunction optical array, a
4 diffractive optical element, a beam shaper, a microlens array, an optical diffuser, a beam
5 splitter, a laser diode corrector, a fine pitch grating, a photonic crystal, a micro-electrical-
6 mechanical system, micro-circuitry, a micro-surface-acoustic-wave device, a micro-
7 mechanical oscillator, a polymerase chain reaction microsystem, a biochip for detection of
8 hazardous chemical and biological agents, or a high-throughput drug screening and
9 selection microsystem.

1 72. The method according to claim 70, wherein step (f) includes the
2 steps of:

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3 f1) ablating a second calibration mark in the alignment surface of the
4 repair mount with the micro-machining laser, the second calibration mark located such
5 that centers of the two calibration marks are a predetermined distance apart;

6 f2) determining a location of a center of the second calibration mark in
7 the alignment image;

8 f3) determining the constant distance based on a number of pixels
9 between the centers of the two calibration marks in the alignment image; and

10 f4) using the locations of the centers of the two calibration marks in the
11 alignment image and the constant distance determined in step (f3) to define the image
12 coordinate system for the imaged surfaces.

1 73. The method according to claim 70, wherein:

2 the constant distance is a predetermined distance; and

3 step (f) includes using the location of the center of the calibration mark in
4 the alignment image, the matrix of pixels, and the constant distance to define the image
5 coordinate system for the imaged surfaces.

1 74. The method according to claim 70, wherein:

2 the defective microstructure includes two reference marks, located such that
3 the two reference marks have respective centers that are a predetermined distance apart;
4 and

5 step (f) includes the steps of;

6 f1) determining the constant distance based on a number of
7 pixels between the centers of the two reference marks in the alignment image; and

8 f2) using the location of the center of the calibration mark in the
9 alignment image and the constant distance determined in step (f1) to define the
10 image coordinate system for the imaged surfaces.

1 75. The method according to claim 70, wherein:

2 the submicron defect of the defective microstructure is formed of the device
3 material, which has a device machining threshold;

4 the alignment surface of the repair mount is formed of an alignment
5 material having an alignment ablation threshold, the alignment ablation threshold being
6 less than the device machining threshold;

7 step (c) includes operating the micro-machining laser with an alignment
8 peak fluence to ablate the calibration mark in the alignment material of the alignment
9 surface, the alignment peak fluence being less than the device machining threshold and
10 greater than the alignment ablation threshold; and

11 step (j) includes operating the micro-machining laser with a repair peak
12 fluence to repair the submicron defect in the device material of the defective
13 microstructure, the repair peak fluence being greater than the device machining threshold.

1 76. The method according to claim 70, wherein:

2 a light beam of the micro-machining laser propagates along a beam path
3 including;

4 a transversely moveable pinhole mask having a pinhole located in the
5 beam path; and

6 reducing optics to produce the beam spot on the top surface of the
7 defective microstructure and the alignment surface of the repair mount having a
8 beam spot diameter smaller than a pinhole diameter of the pinhole; and

9 step (i) includes aligning the beam spot of the micro-machining laser over
10 the portion of the submicron defect of the defective microstructure by moving the
11 transversely moveable pinhole mask a scaled amount based on a ratio of the pinhole
12 diameter to the beam spot diameter.

1 77. The method according to claim 70, wherein step (i) includes aligning
2 the beam spot of the micro-machining laser over the portion of the submicron defect of the
3 defective microstructure by moving the repair mount.

1 78. The method according to claim 70, wherein the micro-machining
2 laser is one of an ultrafast laser or an excimer laser.

1 79. The method according to claim 70, wherein:

2 the microstructure to be repaired includes micro-circuitry; and
3 the submicron defect is a short circuit.

1 80. The method according to claim 70, wherein:

2 the micro-machining laser is an ultrafast laser;
3 a full width at half maximum (FWHM) of the beam spot of the micro-
4 machining laser on the top surface is diffraction limited; and

5 step (j) includes operating the micro-machining laser with a machining
6 fluence to machine the device material of the submicron defect, the machining fluence
7 being such that a diameter of an area of the top surface machined by a pulse of the
8 ultrafast laser is less than the FWHM of the beam spot.

1 81. The method according to claim 70, wherein machining the device
2 material in step (j) includes one of ablating the device material or permanently altering a
3 structure of the device material.

1 82. A method for pre-calibration of a laser micro-machining system to
2 achieve alignment tolerances greater than a diffraction limit of an illumination wavelength
3 used during pre-calibration for machining of pre-existing microstructures including at least
4 one submicron feature, the method comprising the steps of:

5 a) mounting an alignment blank in the laser micro-machining system,
6 such that a beam spot of a micro-machining laser of the laser micro-machining system is
7 incident on a top surface of the alignment blank;

8 b) ablating a first calibration mark and a second calibration mark in the
9 top surface of the alignment blank with the micro-machining laser, the two calibration
10 marks located such that centers of the two calibration marks are a predetermined distance
11 apart;

12 c) illuminating the top surface of the alignment blank with light having
13 the illumination wavelength;

14 d) imaging the top surface of the alignment blank with a digital camera
15 to produce an alignment image of the top surface which includes a matrix of pixels, the
16 alignment image being scaled such that each pixel has a width corresponding to a constant
17 distance on the imaged surface, the constant distance being less than half of the
18 illumination wavelength;

19 e) determining the constant distance based on a number of pixels
20 between the centers of the two calibration marks in the alignment image;

21 f) determining locations of centers of the two calibration marks in the
22 alignment image and using the locations of the centers of the two calibration marks in the
23 alignment image and the constant distance determined in step (e) to define an image
24 coordinate system for surfaces imaged by the digital camera;

25 g) using the location of the center of the second calibration mark in the
26 alignment image and the image coordinate system defined in step (f) to determine initial

27 coordinates of the beam spot of the micro-machining laser in the image coordinate
28 system;

29 h) removing the alignment blank from the laser micro-machining
30 system; and

31 i) mounting one of the pre-existing microstructures to be machined in
32 the laser micro-machining system, such that a beam spot of the micro-machining laser is
33 incident on a machining surface of the one pre-existing microstructure.

1 83. The method according to claim 82, wherein the pre-existing
2 microstructures to be machined include at least one of a microstructure mold, a quantum
3 cellular automaton, a coupled quantum dot device, a resonant tunneling device, a
4 multifunction optical array, a diffractive optical element, a beam shaper, a microlens array,
5 an optical diffuser, a beam splitter, a laser diode corrector, a fine pitch grating, a photonic
6 crystal, a micro-electrical-mechanical system, micro-circuitry, a micro-surface-acoustic-
7 wave device, a micro-mechanical oscillator, a polymerase chain reaction microsystem, a
8 biochip for detection of hazardous chemical and biological agents, or a high-throughput
9 drug screening and selection microsystem.

1 84. The method according to claim 82, wherein a light beam of the
2 micro-machining laser propagates along a beam path including:

3 a transversely moveable pinhole mask having a pinhole located in the beam
4 path; and

5 reducing optics to produce the beam spot on the surfaces imaged by the
6 digital camera having a beam spot diameter smaller than a pinhole diameter of the
7 pinhole.

1 85. The method according to claim 82, wherein the micro-machining
2 laser is one of an ultrafast laser or an excimer laser.